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LARGE SCALE PROPAGATION TESTS
RECOMMENDED NON-PROPAGATING DISTANCES
FOR AN, ANFO, AND DYNAMITE RECEPTORS

by
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*(A short film was presented by Dr. Van Dolah at the beginning of the presentation)

The objective of the test program you have witnessed in Dr. Van Dolah's presentation was to establish safe separation distances for ammonium nitrate (AN) and ammonium nitrate fuel oil (ANFO) receptors from high explosive donors. The chore of extrapolating the test data to provide the required separation tables fell upon an ad hoc industry committee chaired by Mr. H. W. Backes, Monsanto Chemical Co., St. Louis, Mo. The industry members of the Committee comprised Dr. W. J. Taylor, Atlas Chemical Industries, Wilmington, Delaware; Mr. Sam Porter, Explosives Engineering consultant, Arlington, Virginia; and Mr. F. A. Loving, du Pont Co., Wilmington, Delaware. The group was assisted and advised by the authors of the U. S. Bureau of Mines reports of the test program--Dr. R. W. Van Dolah, Mr. F. C. Gibson, and Mr. J. N. Murphy, U. S. Bureau of Mines Explosives Research Center, Pittsburgh, Pa. I should like to briefly summarize the extrapolation problems facing this group and the basis for the final recommendation produced.

One problem is obvious immediately in a plot of the data from the test shown in Figure 1. The experimental 50% propagation points for the charge weights tested did not support the cube root scaling law usually employed in tables of distance. A number of explanations were considered. One might first question the validity of cube root scaling in propagation tests. It is certainly well documented that peak pressure scales in accordance with this law. However, blast impulse scales differently, and it would be surprising if missile velocity over large gaps would obey strict cube root scaling. A great deal of small scale testing with dynamite and commercial explosives had indicated that cube root scaling was valid. However, in much of the early work of this type, only the donor charge was scaled to large charge weights; and the receptors were small. Since the probability of initiation is clearly a function of receptor size where missiles are involved, one disturbing question was

whether or not standard propagation tables such as the American Table of Distances (ATOD) intermagazine spacings were properly drawn. The Barksdale test program only evaluated dynamite receptors at one distance; consequently, experimental shots at another size were undertaken by a du Pont laboratory. The results are shown in Figure 2. Our tests at the 23-lb. level were made with a scaled geometry corresponding to the Barksdale test. The donor was again ANFO with multi-point initiation. The tests with metal missiles employed thinner metal ends, also scaled from the thickness used in the large tests. The slopes of .3 and .38 obtained appear to indicate that, at least for sensitive explosives, cube root scaling is acceptable. In fact, I have extended the non-missile line, and you will note that it predicts 50% propagation in a half cartridge sensitiveness test of about 20-in. for a half cartridge weight of about 1/4-lb. This value is typical for the grade of dynamite used.

The Committee gave some consideration to the use of a $W^{2/3}$ scaling for the less sensitive AN and ANFO receptors. While this is clearly a conservative basis of extrapolation, the resulting prediction for very large charge weights would indicate greater sensitivity for AN and ANFO than the American Table of Distances indicates for dynamite.

The American Table of Distances has provided adequate distances for many decades of use. Furthermore, the non-missile large scale test with dynamite appears to confirm the intermagazine distance of the American Table of Distances at the 1600-lb. level. Since approved magazine construction requires bullet resistant walls for dynamite storage, the non-missile propagation distance applies. The large scale test indicated a 50% propagation point for dynamite of 67-ft. Using the safety factor suggested by the Bureau of Mines data analysis; namely, an increase of 40%, one obtains 94-ft. for a non-propagating distance. The American Table of Distances prescribed 86-ft. for the separation of unbarricaded magazines containing 1600-lbs. It thus appears that the tests provide reasonably good support for at least this portion of the American Table of Distances. Figure 3 is a plot of the American Table of Distances taken from the Bureau of Mines report. It will be seen that constant cube root scaling was not employed for intermagazine spacings at very large charge weights. Thus, some allowance was made many years ago in anticipation of larger than scaled propagation distances for very large donors and receptors.

A further consideration was that the experiments were designed to model a segment of a larger mass of detonating material by means of plane wave (multipoint) initiation and aiming the donors along the direction of propagation of the detonation. This design certainly represents a "worst case" for extrapolation purposes.

In consequence of these considerations, our Committee chose to base recommended storage distances for AN and ANFO upon those used in the American Table of Distances (intermagazine spacings) in the following manner: the 50% propagation distances for dynamite were compared to those

obtained with AN and ANFO; factors for relative sensitiveness were obtained and applied to the American Table of Barricaded Intermagazine Distances. Since a primary objective was to provide for safe operation of field storage and mix plants typically comprising mixers, carload quantities of prilled AN and truckloads of ANFO, missile propagation was given greater weight in establishing the ratios of sensitivity. Barricaded distances for the recommended storage for the prilled AN were set at 1/6 of those prescribed for dynamite; distances for ANFO were set at 6/10 of the distance for dynamite; and finally, unbarricaded storage requires an increase of 6 times the barricaded distance. Also included in the tables promulgated is an indication of minimum barricade thickness required. These thicknesses are scaled from the test thicknesses employed at Barksdale with the cube root of the charge weights.

The tables obtained have been adopted by the National Fire Protection Association (NFPA) as a tentative standard for consideration in industry. Subsequent review by many companies and agencies concerned indicates that the prescribed distances and barricade thicknesses are acceptable as permanent standards. The Committee further undertook to provide explanatory notes and advice on the application of the tables to typical situations. Examples were added prescribing treatment of combined masses of material where propagation could occur between two or more masses. Please note that this publication is a <u>tentative</u> standard and hence subject to further revision. Your suggestions for revision are solicited and should be forwarded to the NFPA by September 11, 1967. Copies of the tentative standard can be obtained from the NFPA, 60 Batterymarch Street, Boston, Mass. 02110 for 60¢ per copy.

Two examples used in the NFPA tentative standard are illustrated in Figure 4. Potential donors are the material in and near an ANFO mixer and the product being accumulated in trucks. Without a barricade, either of these donors can initiate the AN rail car as well as each other, and the potentially explosive storage equals the sum of all three masses. The FGAN is considered one half as potent as ANFO, making the total explosion potential 132,500 lbs. With the AN car barricaded, the donors considered separately or jointly will not initiate the AN and the explosion potential is reduced to 82,500 lbs.

Figure 1

PLOTS OF S_{50} VALUES VERSUS CHARGE WEIGHTS

From US BUREAU of MINES Report of INVESTIGATION 6903
by R.W. Van Dolah, F.C. Gibson, and J.N. Murphy.

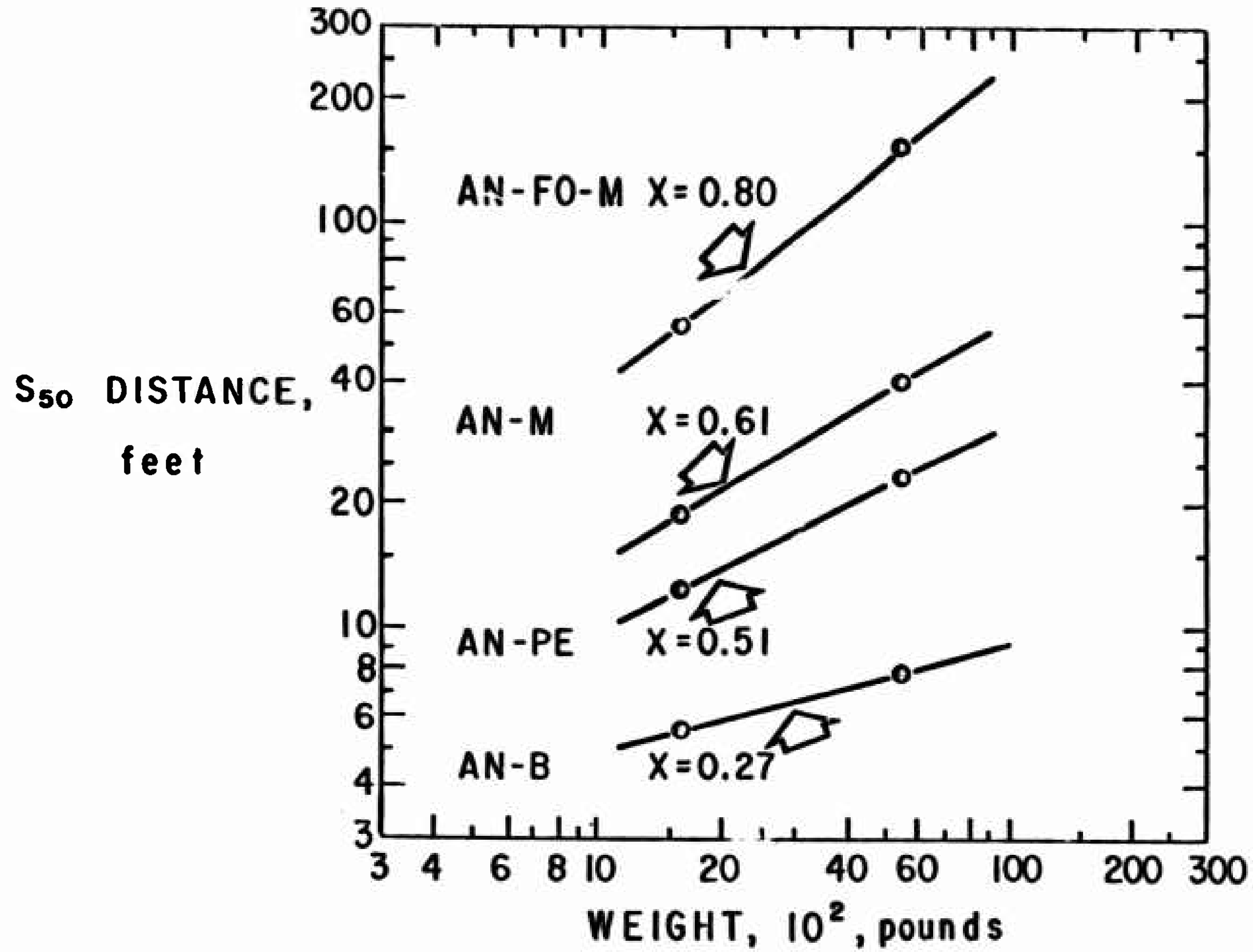


Figure 2

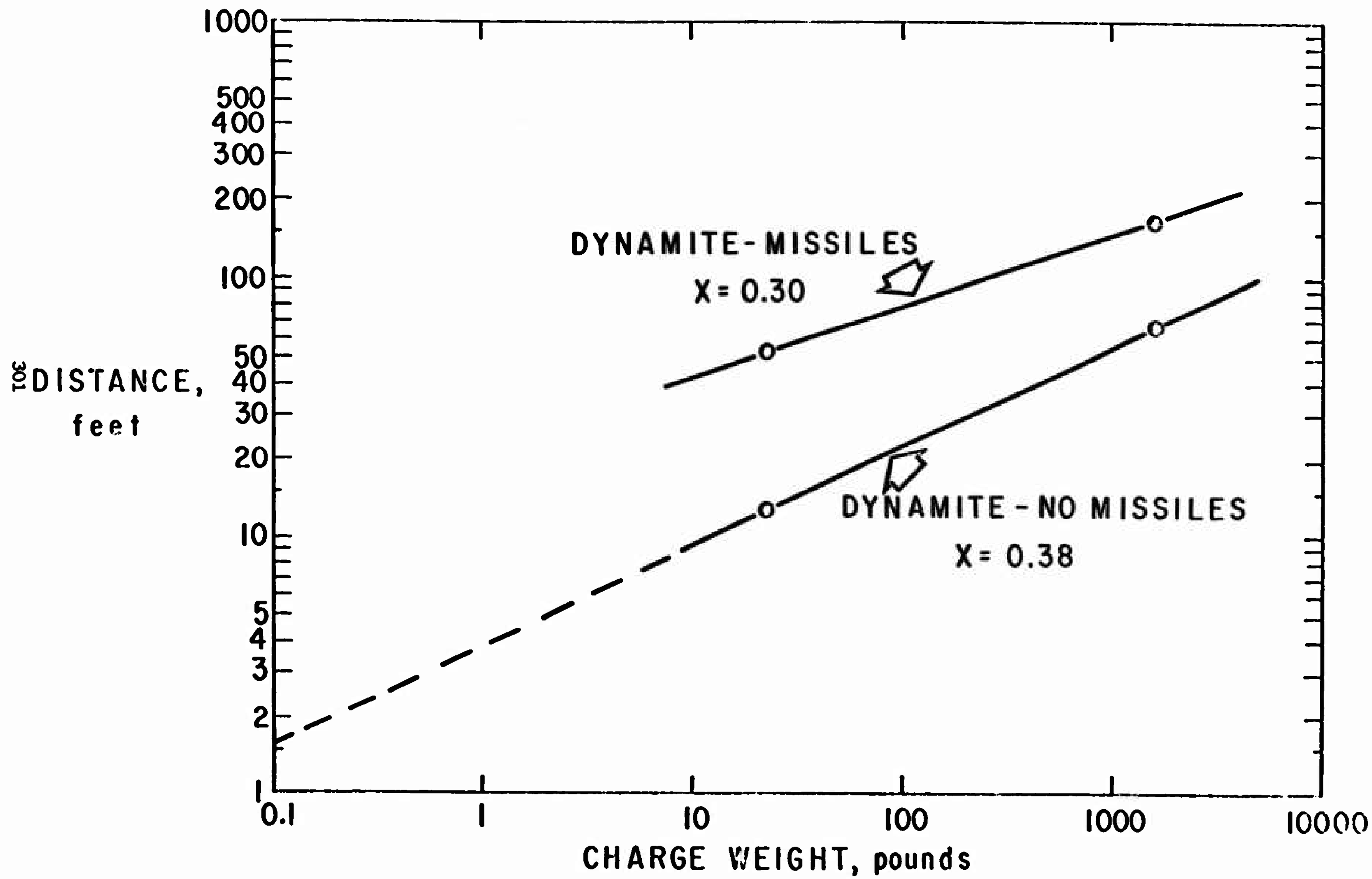

DYNAMITE-MISSILES
X = 0.30
DYNAMITE - NO MISSILES
X = 0.38
DISTANCE, feet
1000
500
400
300
200
100
50
40
30
20
10
5
4
3
2
1
0.1
1
10
100
1000
10000
CHARGE WEIGHT, pounds

Figure 3

PLOT OF AMERICAN TABLE OF DISTANCES SHOWING THREE VALUES OF THE EXPONENT IN THE EQUATION $S = F(W^X)$

From US BUREAU of MINES Report of INVESTIGATION 6903 by R.W. Van Dolah, F.C. Gibson, and J.N. Murphy.

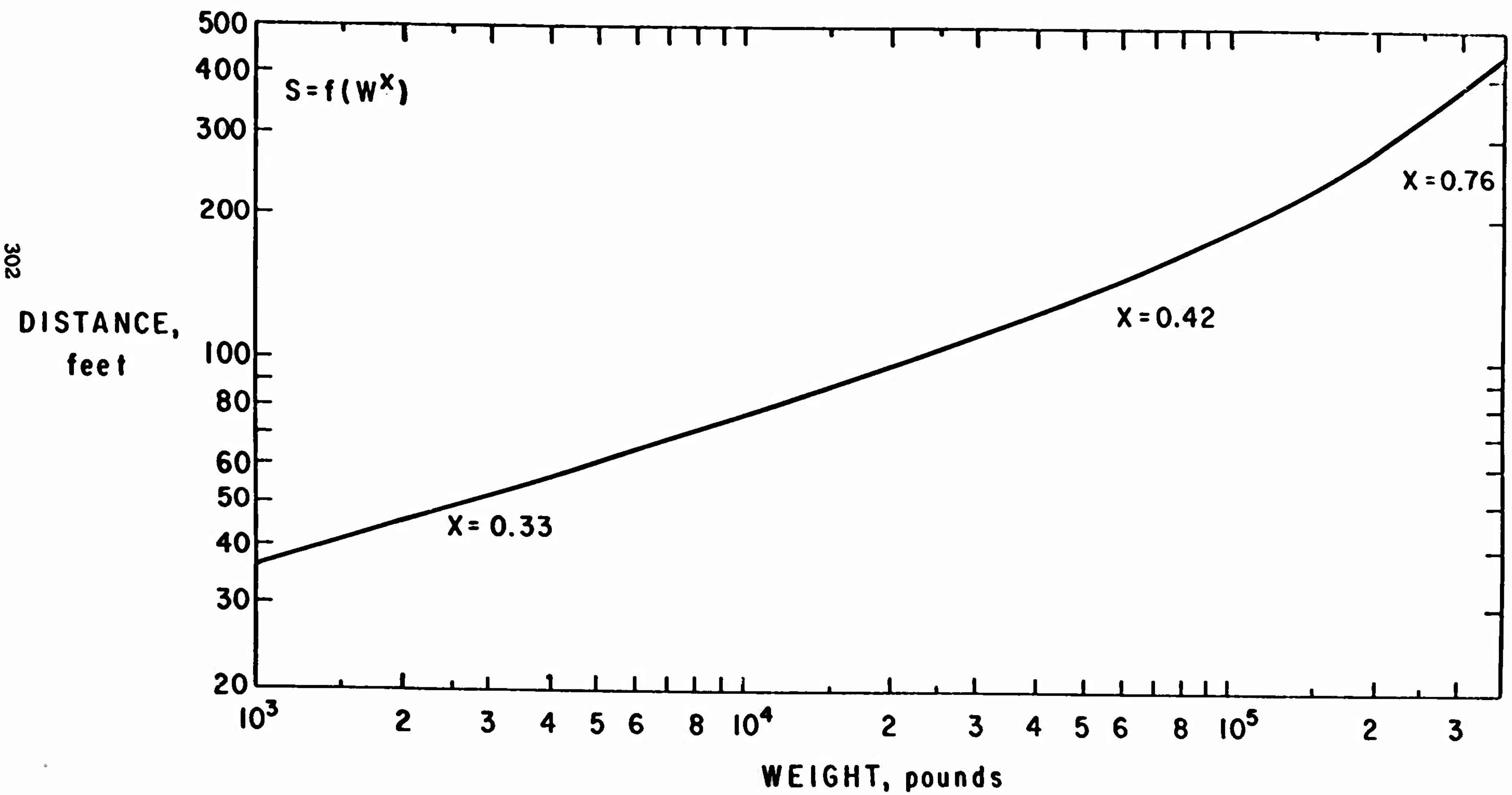
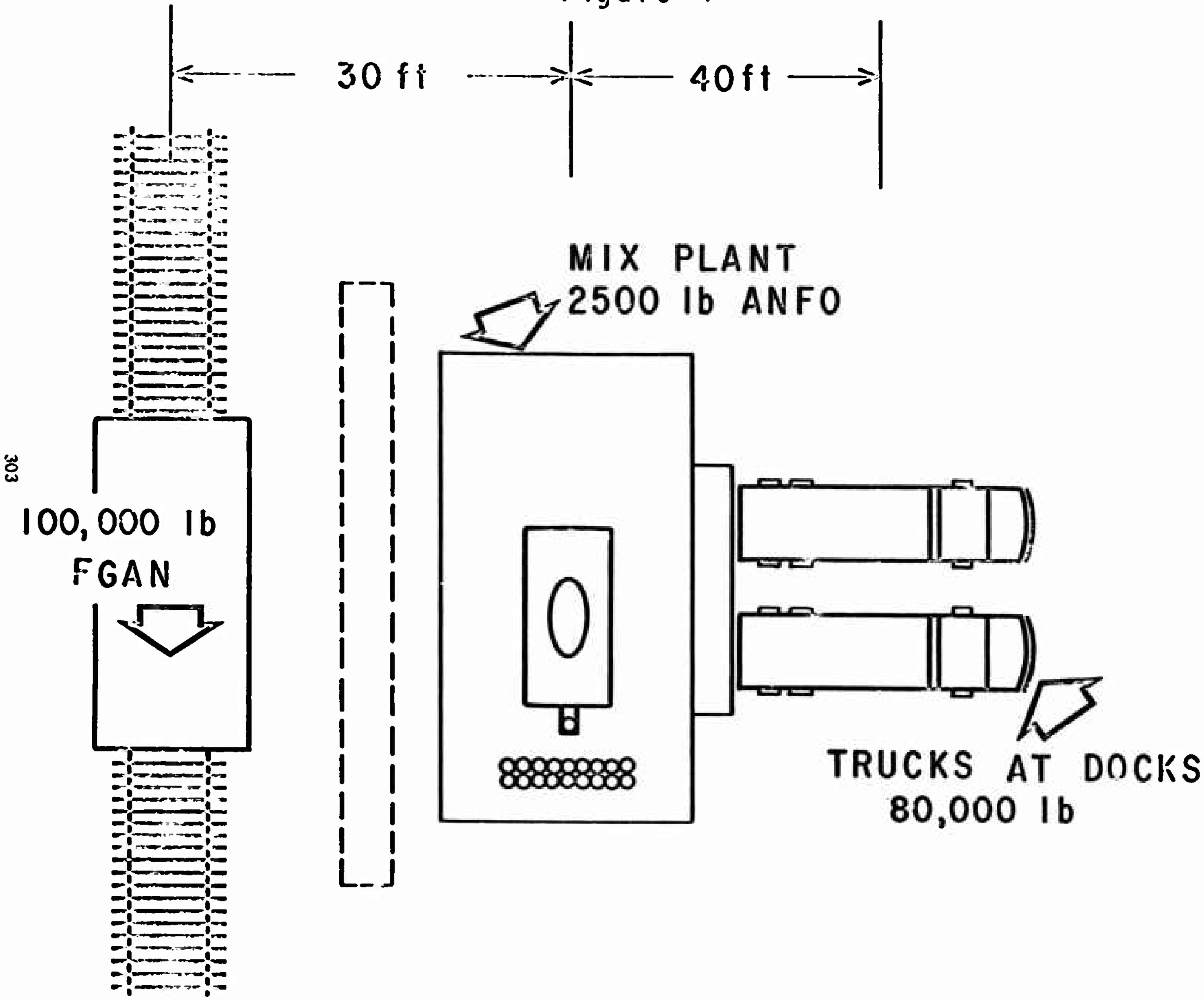


Figure 4


30 ft
40ft
MIX PLANT
2500 lb ANFO
100,000 lb
FGAN
TRUCKS AT DOCKS
80,000 lb

DR. C. B. DALE, NOS INDIAN HEAD, MD.: I noted on that last slide where you had the trucks placed next to the mixer building that you were measuring from the middle of the trucks to the middle of the mixer building, rather than from the edge of these various components. Can you explain that?

LOVING: Yes, this is one of the areas where I think our committee may have gotten in a little trouble. I mention this in passing. In order to deal with the situation of how to treat combined masses as a donor, we chose to use a center of mass calculation in our examples so that both the individual and combined masses could be independently checked as donors. In this case where the very large mass is farther away, it is obviously unfair to charge the mixer with the total mass. On the other hand, there are situations, particularly in elongated storage like those trucks, where the center of mass does not appear to be the right answer either. And again, in application of the tables, this is the subject that the committee itself will propose a change. We chose initially the center of mass and we checked to be sure we weren't in trouble but I think we are. Not in trouble in the sense that we are prescribing distances too close, but in trouble because our examples don't fit all the combinations that are possible.

L. W. PHILLIPS, NORTH AMERICAN AVIATION: Regarding the test, what actually was considered to be the cause of detonation of the acceptor charge? Was it the flying particles, was it that these particles were hot from the donor detonation, or exactly what did cause the detonation of the acceptor charge?

VAN DOLAH: We agree completely with the first paper this morning that initiation is by fragment and the air blast at these distances is far too weak to effect initiation of these materials. The particles are very hot but they are also traveling at a sufficient velocity that their impact pressure would cause the initiation if they were cold.

PHILLIPS: The reason I ask this question is, having had some experience with ammonium nitrate loading drill holes, blasting drill holes, the method to load the hole was to, under about 40 or 50 psi, impact the drills into the hole in order to get compaction for detonation breakage of the rock and I just wondered what actually caused this detonation in the test?

VAN DOLAH: In that operation, you were dealing, at most, with impact pressures of 100 lbs. per square inch. Here we're dealing with literally tens of kilobars impact pressures which are up in the 100,000 pounds per square inch pressures. Its quite a different situation.

SUPPLEMENTARY

INFORMATION

NOTICE OF CHANGES IN CLASSIFICATION, DISTRIBUTION AND AVAILABLITY

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